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A Three-Dimensional Acoustic Site Surveying Probe

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ABSTRACT

A new acoustic site surveying probe is being developed. The device rests on the seabed during the investigation and is controlled remotely from a supporting vessel. Multi-channel digital data is processed on a personal computer. The final data is displayed as a three dimensional image of a five meter diameter cylinder of marine soils. The accuracy of the temporal and spatial resolution of the data may provide the direction and confidence needed to translate acoustic responses into physical and behavioral properties of marine soils.

I. INTRODUCTION

Development of offshore facilities in a safe and cost-effective manner requires a knowledge of the nature and behavioral properties of the seabed. Offshore site investigations are conducted to such acquire information as: seabed topography; geotechnical engineering soil properties; the presence of sub-surface hazards such as shallow gas and loose glacial till; and, the depth and distribution of ice scours in ice prone areas. Costly losses can result if the engineering properties of the seabed are not accurately determined. Thus there is a growing demand for more accurate three dimensional, qualitative and quantitative representations of subsurface properties [1].

Over the past several years a phased approach to site characterization has emerged to better evaluate the inherent variability of marine sediments [2]. Such a program may include: geotechnical drilling; surficial sediment sampling; *in situ* geotechnical testing such as cone penetration and self-boring pressuremeter testing; and, seismic sub-bottom profiling.

A new acoustic site surveying technique is being researched at the Centre for Cold Ocean Resources Engineering at Memorial University of Newfoundland. This technique is based on the Acoustic Sub-Seabed Interrogator (ASI™) concept [2] [3] [4] [5], which involves very precise on site imaging of near surface sediment and the statistical estimation of a soil's homogeneity.

A shallow water prototype probe has been developed to further the ideas of an ASI™ and to establish the limitations inherent in this technique. The prototype rests on the seabed during the investigation and is controlled remotely from a supporting vessel. Tunable, broadband acoustic sources, the stationarity of source and receiver during the investigation, and very fast sample rates, all contribute to the acquisition of precise acoustic images. Conventional multi-channel digital seismic data processing techniques, running on a personal computer, are used to process the data as it is being acquired. The final data is displayed as a three dimensional image of a five meter diameter cylinder of marine soils to an anticipated depth of fifty meters or more. The accuracy of the temporal and spatial resolution of the data should be unprecedented. Therefore inferences on the physical and behavioral properties of the seabed may be possible. A deep water tool will be the focus of future research and development.

The prototype and its control systems will be described in this paper. The operational and investigative procedures will

References and figures at end of paper

be outlined and data from a recent field test will be displayed.

II. SYSTEM DESIGN

The prototype probe has been field tested several times and has undergone extensive development and refinement. It is now a fully functional, diver assisted, prototype capable of operating in water depths of 30 meters. The modular design permits rapid disassembly for transportation and storage.

The probe is an octagonal structure approximately 5 meters in diameter and 2 meters in height (Fig. 1). It weighs approximately 1800 kg in air and 800 kg in salt water. An outer rigid frame, comprised of four quarter sections, is constructed of 1.5 in. and 3 in. aluminum pipe. An interior network of ultra high molecular weight (UHMW) polyethylene crossbracing is bolted to the aluminum structure and to a central aluminum hub. This aluminum and polyethylene network provides the structural integrity for the probe and supports sixteen acoustic sources and receivers. The probe sits on four self-adjusting legs to ensure that it is firmly in contact with an uneven seabed.

One hydrophone is positioned directly beneath each of the sixteen acoustic sources. A hydrophone positioning system rotates four additional hydrophones, located on an extended beam, about a central sleeve bearing. The acoustic data is transmitted through a hydrophone networking system to the surface by way of a multi-conductor cable.

High voltage energy is delivered to the acoustic sources from a shipboard seismic energy power supply. A power distribution system allows the operator to select and fire any one of the sixteen sources.

The open inner structure was designed to minimize interference with the acoustic measurements. Several aluminum underwater housings, containing control systems necessary for the remote operation of the probe, are bolted to the outer aluminum frame.

A description of the acoustic sources and the major control systems follows.

ACOUSTIC SOURCE: To attain the desired precision in acoustic measurements a source was required that consistently delivered a high frequency, broadband pulse that could be tuned to a particular seabed. We have developed a unique acoustic source based on the conventional multi-electrode sparker [6]. Our device represents a radical departure from conventional sparker designs. The design incorporates a stainless steel plate (high potential), a symmetrical array of 121 stainless steel tips (low potential) and a high density polyethylene housing filled with petroleum wax (Fig. 2).

The amplitude and bandwidth of the emitted signal can be manipulated by varying the energy delivered to the source. Thus the temporal resolution, or vertical discrimination ability, of the pulse can be controlled. "Free field" calibration experiments show that typical output is composed of 3.0 kHz centre frequency with an 4.2 kHz bandwidth measured 3 dB down at an operating power of 480 Joules (Fig. 3). Note the shape of the acoustic pulse and the corresponding phase diagram. The pulse is very "front end loaded", exhibiting minimum phase characteristics necessary for digital deconvolution techniques. It has also been demonstrated that the source can be operated for extended periods of time with little change in its signature.

POWER DISTRIBUTION SYSTEM: The power distribution system enables the operator to fire any one of the sixteen acoustic sources. The high voltage capacitive discharge from the seismic energy power supply is supplied to the probe via a co-axial transmission cable (Fig. 4). At the probe the "hot" and "ground" sides of the circuit are separately directed into two water-tight aluminum housings. These housings contain normally open high voltage mercury displacement relays. By closing the appropriate relays, the high voltage energy is distributed to individual acoustic sources. Auxiliary electronics in the aluminum housings decode binary information, supplied from a shipboard control module, which designates which relay to close, distributing the high voltage to the selected acoustic source.

HYDROPHONE POSITIONING/NETWORKING SYSTEMS: At present twenty hydrophones are positioned on the probe. One hydrophone is positioned directly beneath each of the sixteen acoustic sources so that zero offset or normal incidence data is acquired. These hydrophones are arranged in four linear banks, each containing four hydrophones. Four additional hydrophones are positioned on the extended rotating beam, forming a fifth bank of mobile hydrophones (Fig. 5). These hydrophones, which provide the offset information required for velocity determinations, are remotely positioned in one of eight preselected locations by the hydrophone positioning system (Fig. 4). All hydrophones are suspended from the frame via flexible nylon harnesses which dampen oscillations that are transmitted through the probe.

The hydrophone positioning system consists of; the hydrophone beam on which the mobile hydrophone bank is mounted, a central PVC sleeve bearing about which the beam is rotated and a DC stepper motor and wheel assembly which drives the beam about a circular track. A shipboard motor controller allows the operator to rotate the beam in either direction. Eight proximity switches, positioned around the circular track, control a surface LED display which permits accurate remote positioning. The stepper motor's holding torque, insures the beam's stability during data acquisition.

Only two of the five banks of hydrophones (eight in total) are simultaneously transmitted to the surface to minimize the size of cable required. The remote selection of hydrophone banks is accomplished by the hydrophone networking system which utilizes switching relays, located in a water-tight aluminum housing. Data is transmitted to the surface via a multi-conductor cable with individually shielded, twisted conductor pairs.

SELF-ADJUSTING LEGS: Four supporting legs, utilizing a closed system of hydraulic fluid, self-adjust on contact with an uneven seafloor. The probe's weight is then equally distributed over the legs. Once on the bottom, the legs are locked in position by blocking the flow of hydraulic fluid. This is accomplished with four solenoid valves, located in another water-tight aluminum housing. Power is supplied to the solenoids from the shipboard control module via the multi-conductor control cable (Fig. 4).

III. OPERATIONAL PROCEDURE

The disassembled probe is transported by truck to a land location near the offshore test site. A team of three people can assemble the prototype in about sixteen hours. The multi-conductor control, stepper motor and hydrophone cables are connected. A boom truck is employed to lower the probe to the seafloor (Fig. 6) Divers raise the probe to the surface by means of a diver controlled ballast system which utilizes a large lift bag and provides continuous automated buoyancy. The probe is towed, suspended from the lift bag, to the preselected seabed test site and lowered to the seafloor. Finally, divers then attach the high voltage power cable. The tool rests on the seabed during data acquisition and processing, remotely controlled via the electrical umbilical cable link to the surface.

While in the design stage it has been advantageous and cost effective to work from the shore. Diver assistance is required for deployment and recovery only. Data acquisition is completely automated. The present dependence on diving support limits the usage of the prototype to water depths of approximately thirty meters.

IV. INVESTIGATION PROCEDURE

The investigation commences after the probe has been positioned on the seabed. The hydrophone beam is rotated into beam position #1 and the eight hydrophones in this line are selected (Fig. 5). Data acquisition is controlled from a 386 portable computer (Fig. 4). The acquisition system also includes: omnidirectional hydrophones with a frequency range of .1 Hz - 180 kHz; charge preamplifiers with built in anti-aliasing filters; and, an eight channel analogue to digital converter with 12 bit accuracy and sample rates up to 2 microseconds. The operator sets the initial gain settings, selects and fires acoustic source #1 (Fig. 5), and displays all eight channels for quality control. Following experimentation to optimise the acquisition and acoustic source parameters, the source is fired a user selected number of times, usually between 25 and 100. The data is summed as it is acquired to improve the signal to noise ratio. Each emitted pulse is monitored for shot to shot consistency via a correlation algorithm. A trace is included into this "running sum" only if the correlation coefficient between successive pulses exceeds a user defined threshold. The reproducibility of the acoustic source permits a high correlation coefficient threshold (.95) to be assigned. All eight channels are then displayed and if acceptable, written to the computers's hard disk.

The same procedure is followed for acoustic sources #2, #3, and #4 to complete data acquisition for beam position #1. The hydrophone beam is then rotated into beam position #5 and data is similarly acquired. Data from these two beam positions are then merged and processed as a complete seismic line, utilizing an "off the shelf" digital seismic data processing package running on a 25MHz Compaq Deskpro 386 personal computer.

This investigation procedure is repeated for the remaining beam positions to acquire a complete data set. At any time throughout the data acquisition the investigator can alter the acquisition parameters and the acoustic source signatures so as to interactively optimize the capabilities of the probe.

V. FIELD RESULTS

The first complete acoustic data set was acquired at a test site in the nearshore waters off Newfoundland in the summer of 1990. The site was located approximately 60 meters from shore in about 11 meters of water. Roughly four meters of stratified coarse sands and gravels overlay bedrock, which consisted of fractured, interlayered sandstone and conglomerate.

The acoustic survey was recorded with a sample rate of 10 microseconds. Analogue anti-alias filters of 0.2 Hz (low cut) and 30 KHz (high cut) were employed. The acoustic sources were fired at two energy settings, 480 joules (referred to as low power) and 1080 joules (high power) so that, effectively, two complete surveys were performed. The source-receiver geometry provided a maximum horizontal fold of four. Coupled with a fifty trace "running sum", each subsurface common depth point (CDP) was sampled a maximum of two hundred times. The processing sequence is shown in figure 7.

A geotechnical field program to acquire physical soil properties at this site followed in the fall of 1990. Two geotechnical boreholes and three seismic cone penetration tests were performed from an anchored float barge. Soil samples were obtained using a conventional split-spoon sampler.

Analysis of these data sets is ongoing. Recovery of soil samples during drilling was poor due to the presence of unconsolidated sands and gravels. As well, the data from the cone penetrometer was limited by its difficulty in penetrating a coarse sand and gravel layer and its refusal at the underlying bedrock. The acoustic data, however, produced an interpretable acoustic response and show a very good correlation to the soils that *were* retrieved. Thus the preliminary results emphasize the need for our technique, particularly in areas of difficult soils such as those at the test site.

Data from these two field programs is shown in figure 8. The good correlation between data sets is indicated. Note the strong acoustic event at 3.7 meters. This does not correspond to a logged stratigraphic boundary. However, no soil sample was recovered in this zone. Three dimensional representations of the acoustic horizons are shown in figure 8e. For this display, subsurface layers have been referenced from a flattened seabed event.

Empirical correlations between the data sets will be established utilizing the multivariate statistical capabilities of a geographic information system (GIS). The limitations inherent in both the acoustic and geotechnical site surveying procedures are now being evaluated.

VI. RESEARCH GOALS

Acoustic data acquired from inhomogeneous soils appears very "noisy" due to the volume reverberation. It is hoped that through the dynamic control of temporal and spatial resolution this "noise" can be quantified to indicate the relative homogeneity of the soil. At present, compression wave acoustic data is acquired and processed as a series of four bisecting two-dimensional seismic lines. The sixteen normal incidence traces are utilized to estimate the homogeneity of the acoustic data over a five meter diameter cylinder. True three dimensional acquisition and processing techniques will be the focus of future research. These will be designed to provide layer-by-layer estimations of specific acoustic properties such as velocity, attenuation, backscatter and reflectivity. As well, a shear wave source will be developed for the probe and the acquisition, processing and analysis of shear wave data will be incorporated into the investigation procedure.

The shallow water prototype provides the vehicle for the examination and advancement of the concepts that embody this site surveying technique. The development of a completely automated, deep water probe is a fundamental goal of this research.

VII. APPLICATIONS

Proposed applications of this new marine site surveying tool include;

i) identification of near surface engineering and drilling hazards such as glacial tills and shallow gas
ii) determination of engineering soil parameters required for the design of offshore structures
iii) marine placer/mineral/aggregate exploration
iv) scientific research

VIII. SUMMARY

A new acoustic probe has been developed which provides the marine geoscience community with a vehicle to acoustically investigate the seabed with unprecedented accuracy. The probe's calibrated response may provide the direction and confidence needed to translate acoustic responses into physical and behavioral properties of marine soils.

Acoustic and physical property data sets were recently acquired at a field site. Preliminary results indicate that the data sets correlate very well. A comprehensive evaluation of the limits inherent in correlating acoustic responses to physical soil properties is ongoing.

ACKNOWLEDGEMENTS

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ASI™ is a trademark of NORDCO Ltd. in association with Dr. Guigné.

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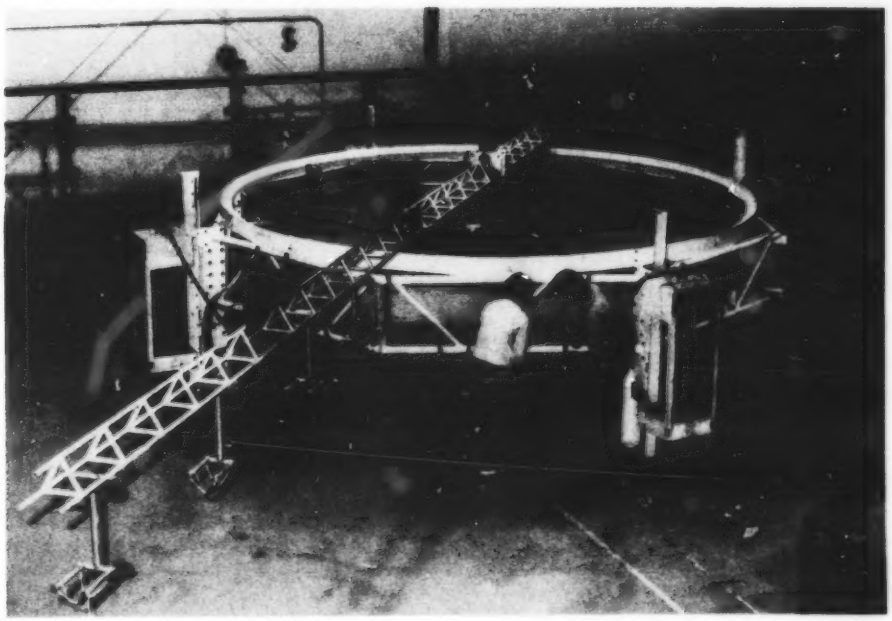

Figure 1: Photograph of Assembled Probe

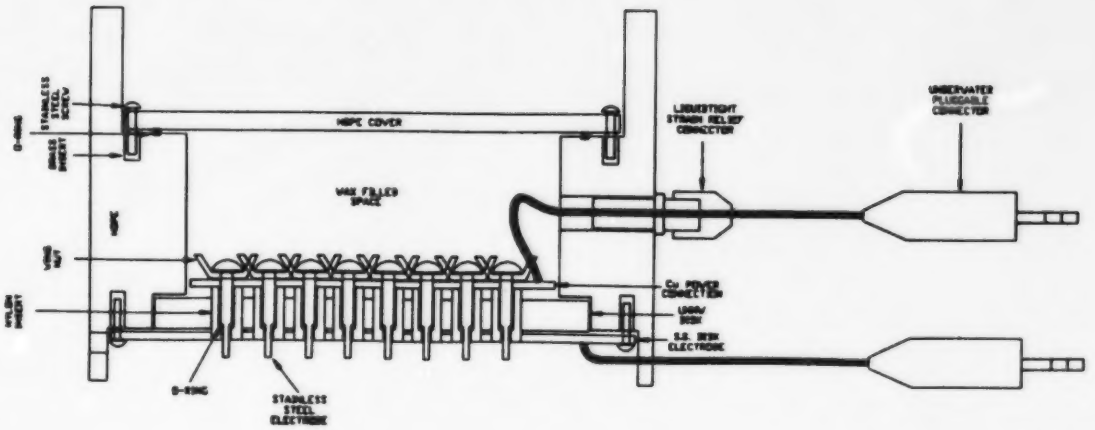

Figure 2: Cross-Sectional Sketch of Sparker

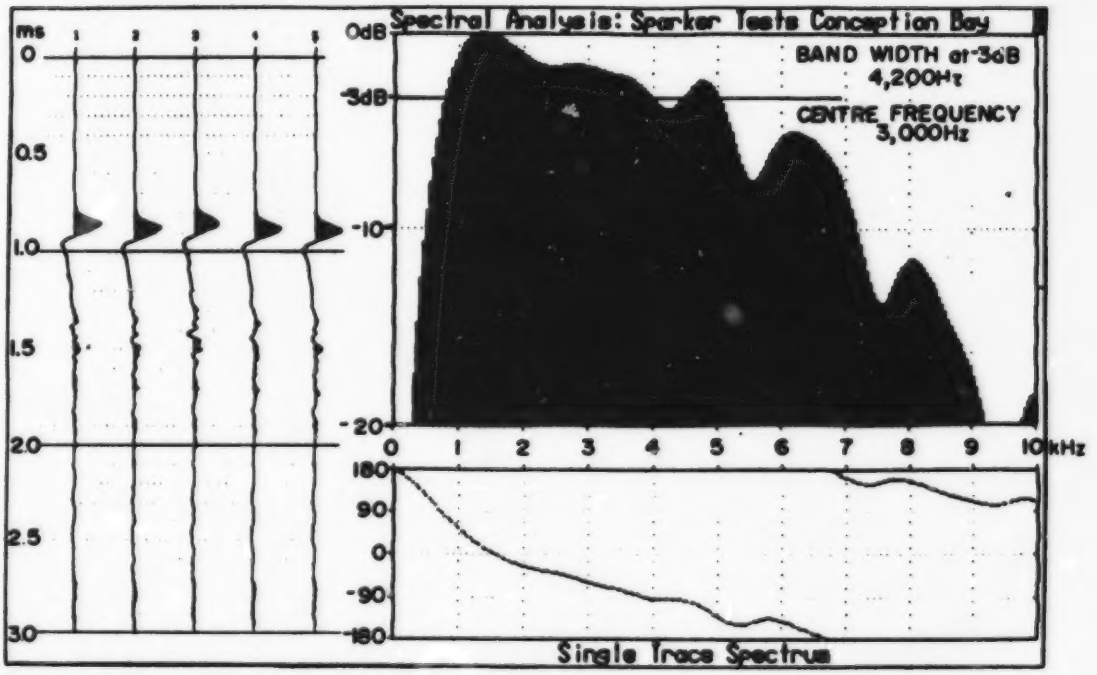

Figure 3: Acoustic Signature; Operating Power 480 Joules

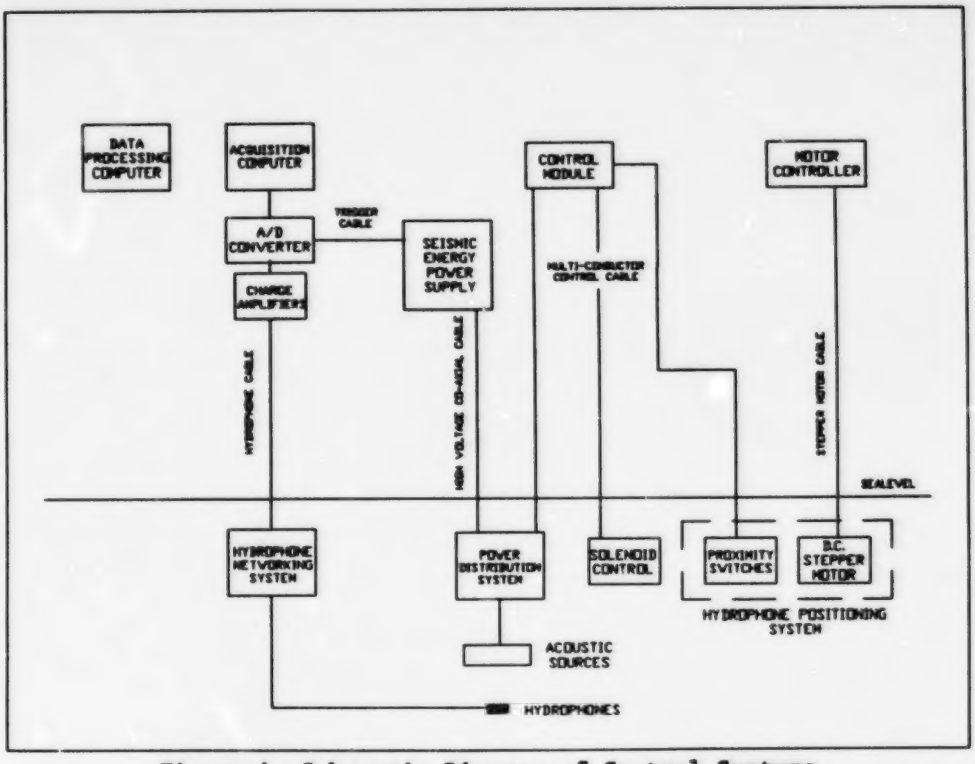

Figure 4: Schematic Diagram of Control Systems

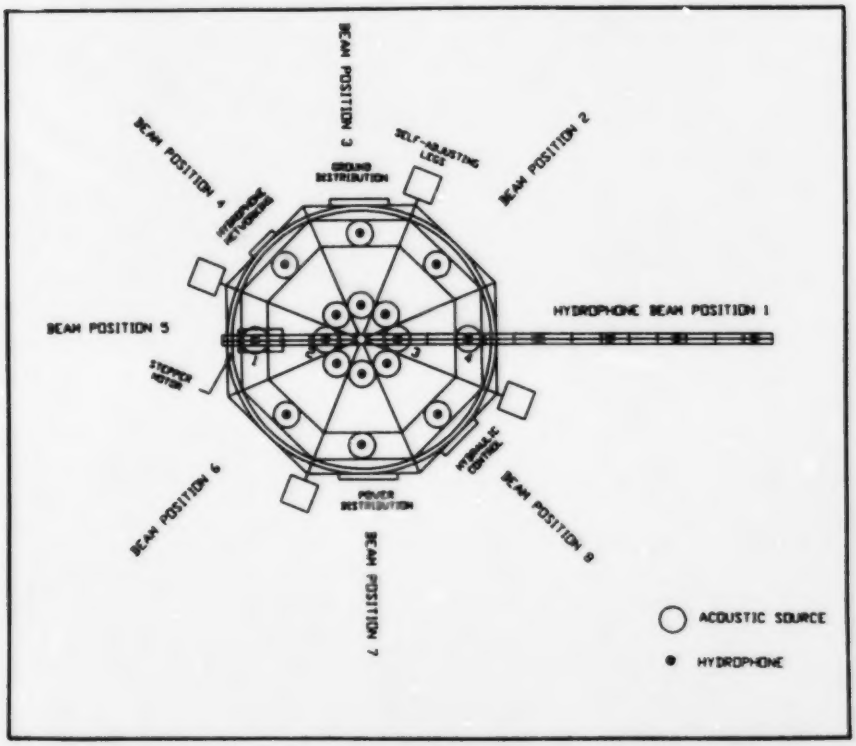

Figure 5: Acoustic Source and Hydrophone Positions

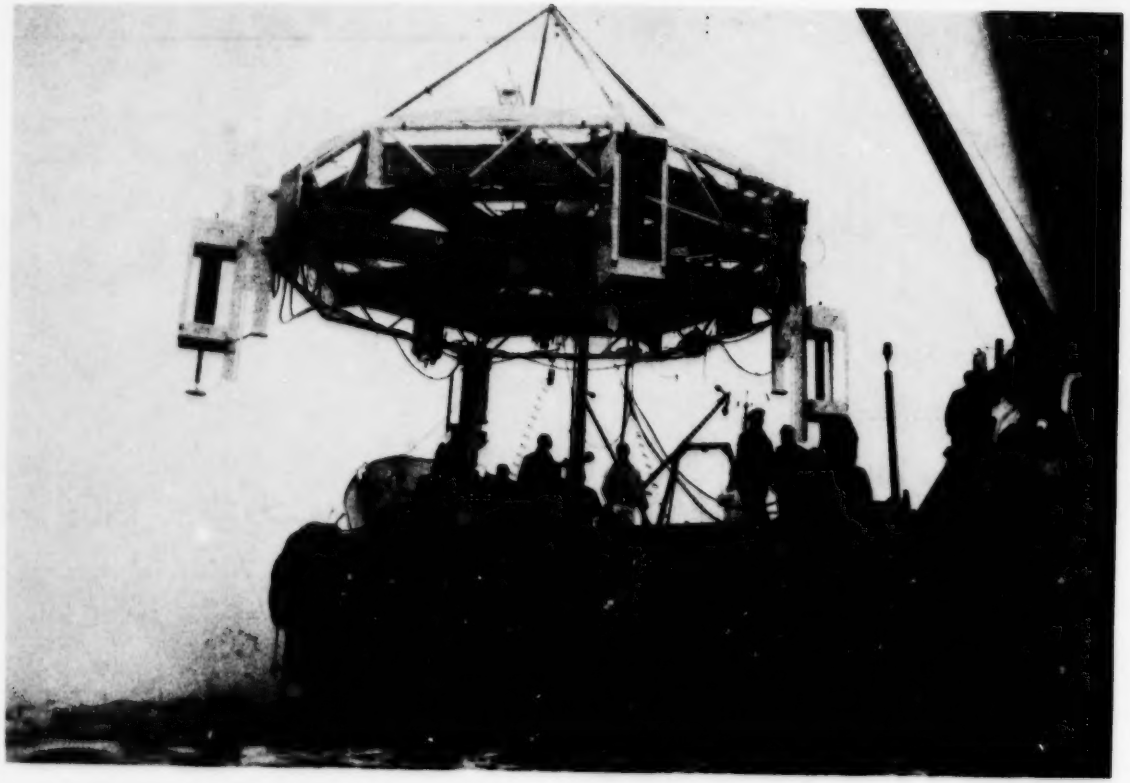

Figure 6: Field Testing

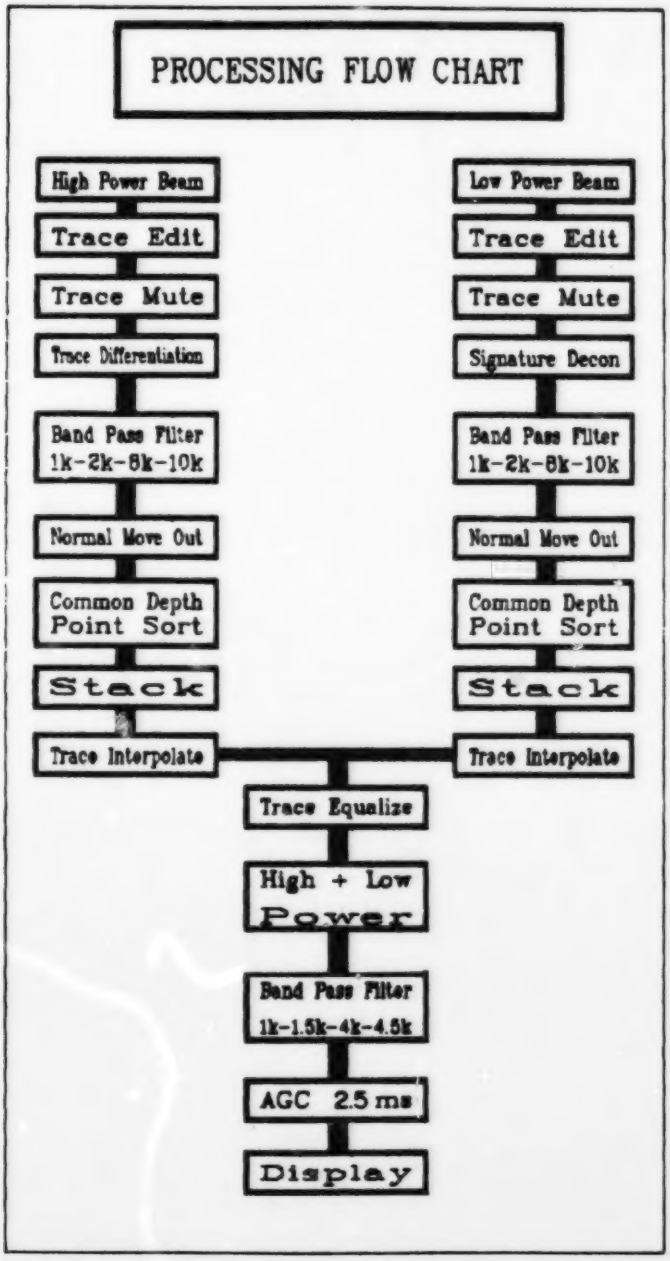

Figure 7: Processing Sequence

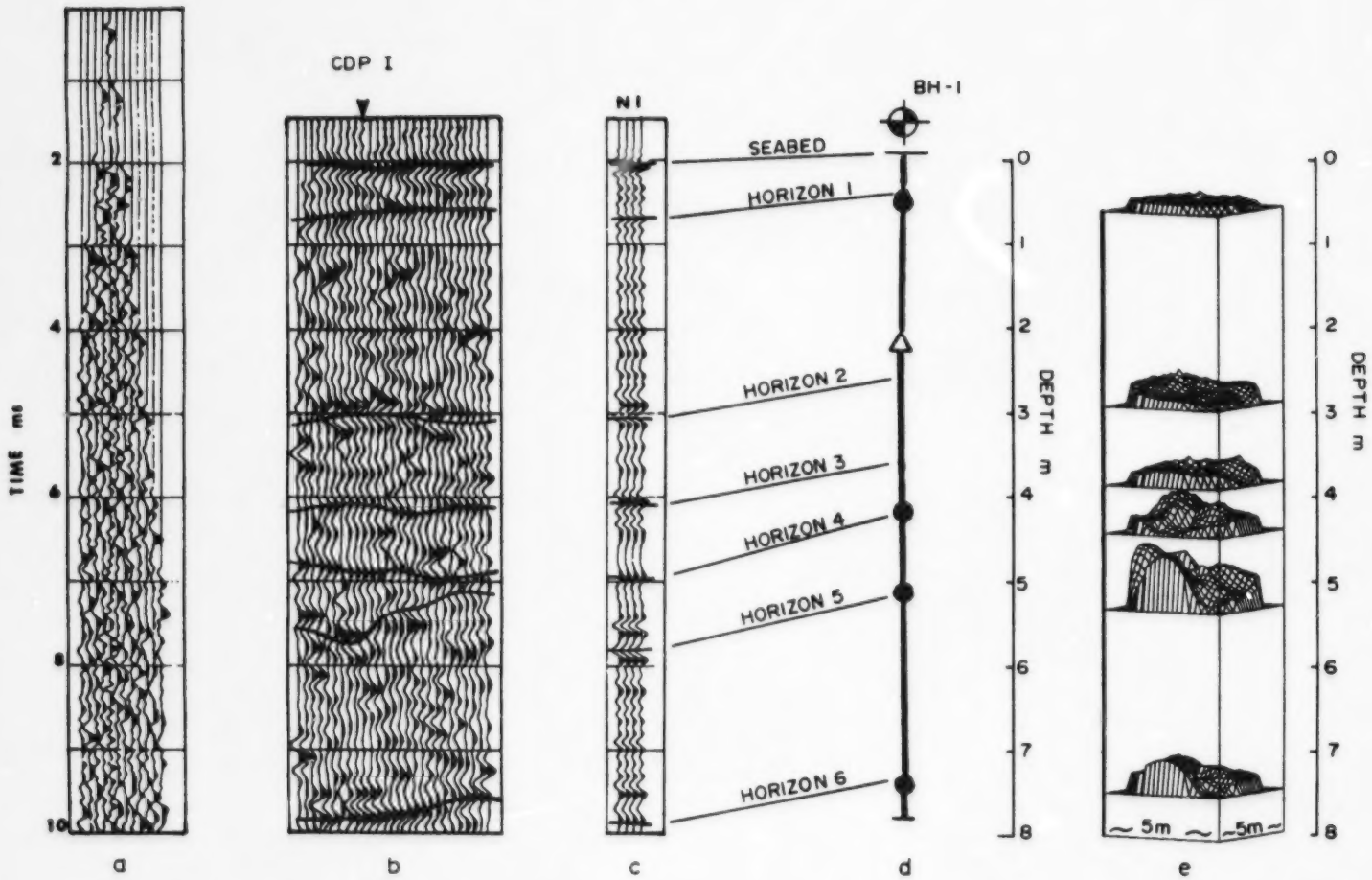

Figure 8: a: Shot Gather, b: Processed Section (one of four), c: Normal Incidence Trace Corresponding to CDP 10 (repeated four times), d: Borehole 1 (corresponding to CDP 10), Represent Stratigraphic Boundaries, Represents Significant Reduction in Cone Bearing Load, e: Three-Dimensional Display of subsurface layers referenced to a flattened seabed event (not shown)